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USE OF FIELD TECHNIQUES TO ASSESS THE ENVIRONMENTAL EFFECTS OF COMMERCIAL NAVIGATION TRAFFIC

by

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Recently completed navigation projects in the United States were responsible for directing the attention of conservation agencies to the impacts of commercial vessel movement. It was suggested that vessel-induced change in magnitude and direction of flow could negatively affect growth, reproduction, and survival of benthic organisms. Laboratory studies demonstrated that mortality or physiological stress to fish larvae or freshwater mussels (family: Unionidae) can be measured under conditions corresponding to high traffic intensity. However, it is difficult to estimate an organismal response to intermittent physical effects, and it is even more difficult to accurately predict long-term responses of natural populations to such disturbances.

The biological consequences of commercial vessel passage should be measured on populations of species in their natural habitats. Studies should provide quantitative data on biotic parameters such as density, relative species abundance, community composition, population demography, and

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rate of growth. Adequate baseline data should be collected; then, additional studies should be conducted to determine whether commercial vessel movement causes measurable change to naturally occurring populations and communities.

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Preface

In October 1985, the US Army Engineer Waterways Experiment Station (WES) initiated a multiyear study on the environmental effects of navigation traffic in large waterways. This work is part of the Environmental Impact Research Program (EIRP), which is sponsored by the Headquarters, US Army Corps of Engineers (HQUSACE). Research consisted of a combination of field and laboratory studies that dealt with larval fishes and juvenile and adult mussels. This report contains a synthesis of most of the pertinent information dealing with mussels and physical effects studies.

Assistance and support were provided by Messrs. Dan Ragland and Robert Whiting of the US Army Engineer District, St. Louis, and Mr. Robert Read of the Wisconsin Department of Natural Resources.

Dr. Edwin A. Theriot was Chief, Aquatic Habitat Group; Dr. Conrad J. Kirby was Chief, Environmental Resources Division; and Dr. John Harrison was Chief, Environmental Laboratory, during preparation of this report. Dr. Roger Saucier, WES, was Program Manager of the EIRP. Technical Monitors were Dr. John Bushman, Mr. David P. Buelow, and Mr. David Mathis, HQUSACE.

Commander and Director of WES was COL Larry B. Fulton, EN. Technical Director was Dr. Robert W. Whalin.

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Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
feet	0.3048	meters
horsepower (550 foot-pounds (force) per second)	745.6999	watts
inches	2.54	centimeters
miles (US statute)	1.609347	kilometers

1 Introduction

Background

In the United States, three projects are responsible for initiating concern over the environmental effects of commercial navigation traffic. These are the Tennessee-Tombigbee Waterway, a connecting link between the Tennessee and Tombigbee Rivers in Alabama and Mississippi; replacement locks and dam in the Mississippi River near Alton, IL; and construction of a new lock in the Ohio River at Gallipolis between Ohio and West Virginia.

During the last 10 years environmental groups and state conservation agencies have directed considerable attention toward the impacts of vessel movement. As a result, much speculation and discussion on this topic has appeared, primarily in the government or nonrefereed literature (Virginia Polytechnic Institute and State University 1975; Academy of Natural Sciences of Philadelphia 1980; Berger Associates, Ltd. 1980; Lubinski et al. 1980, 1981; Sparks, Thomas, and Schaeffer 1980; US Army Corps of Engineers 1980; Environmental Science and Engineering, Inc. 1981, 1988; Simons et al. 1981; Kennedy, Harber, and Littlejohn 1982; Rasmussen 1983; Wuebben, Brown, and Zabilansky 1984; Nielsen, Sheehan, and Orth 1986; Simons, Ghaboosi, and Chang 1987). Much of this writing has been considered speculative (Wright 1982). Regardless, the increasing use of inland waterways to transport bulk commodities (Dietz et al. 1983) and the recent articles on impacts of waterway use in Europe (Brookes and Hanbury 1990, Haendel and Tittizer 1990) suggest that this issue will remain important well into the 21st century.

Purpose

The purpose of this report is to synthesize and discuss some of the recent studies on commercial navigation traffic effects. This report centers on benthic invertebrates, notably the freshwater mussels (family: Unionidae), although other macroinvertebrates and fishes are also referenced. Analysis of traffic effects using laboratory studies, field studies, and modified habitat evaluation procedures is discussed. Recommendations on the most appropriate methods for studying the biological and physical effects of commercial navigation traffic are presented.

2 Physical Effects of Vessel Passage

Changes in Water Velocity

A review of the literature indicates that the pulse of velocity and turbulence associated with vessel passage is a major concern of personnel in conservation groups and resource agencies. It has been suggested that vessel-induced change in magnitude and direction of flow negatively affects benthic organisms by scouring substrates and resuspending fine-grained sediments.

Figure 1 illustrates the change in magnitude and direction of flow caused by passage of a commercial vessel (Miller and Payne 1991b). The vessel was an 800-hp[1] workboat with a 7.5-ft draft and twin 60-in. propellers operating at 900 rpm. It was pushing a single loaded barge upriver in water 13 ft deep. The tow, which requires a 9-ft draft, passed directly over a velocity sensor positioned approximately 9 in. above the substrate-water interface. (The upward pointing arrow depicts the time at which the lead end of the barge passed the sensor.) Vessel passage caused ambient velocity to approximately double for about 100 sec (a change of about 1 ft/sec to slightly more than 1.6 ft/sec) and resulted in a slight alteration in flow direction.

The effects of downbound passage of a tow in the Ohio River near Cincinnati is illustrated in Figure 2. (The lead end of the first barge is delineated with the first arrow; the end of the last barge is depicted with the last arrow.) In this case, the sensor was placed 100 ft from shore, and the vessel was 600 ft from shore. Passage caused an abrupt decline in ambient velocity that lasted approximately 10 sec.

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[1] A table of factors for converting non-SI units of measurement to SI units is presented on page vii.

Downbound passage in the upper Mississippi River caused a more dramatic velocity effect than noted in the above-described tests (see Figure 3). In this test, the vessel passed within 325 ft of the bank, and the velocity sensor was 100 ft from the bank (225 ft from the vessel). Passage of this vessel affected ambient conditions for more than 100 sec, and the flow of the river, normally in a southerly direction (180 deg from north), completely reversed. These disturbances were brought about by displacement of water from the barges, not action of the propellers. None of these figures depicts a period of turbulence immediately after passage of the tow.

The above-described tests dealt with physical effects that originated in the main channel but were measured at a mussel bed along the shore. Commercial vessel movement in the main channel can cause measurable velocity change close to shore, but this is usually not of a magnitude to disrupt the substrate or negatively affect the biota. Details on techniques used to measure these changes in velocity can be found in Bogner, Soong, and Bhowmik (1988), Bhowmik, Miller, and Payne (1990 and references cited therein), and Miller and Payne (1991c). Other physical effects of traffic that could affect aquatic biota are formation of surge waves, turbulence from hull friction or propeller action, water drawdown that briefly exposes shallow-water habitats, and increased shoreline erosion (Johnson 1976; Camfield, Ray, and Eckert 1979; Environmental Science and Engineering, Inc. 1981; Brookes and Hanbury 1990).

Changes in Turbidity

Water samples were collected immediately before and after commercial vessels passed the collection site in the upper Mississippi River (Miller and Payne 1991d, Figure 4). Ambient turbidity was slightly higher in water collected near the substrate-water interface (close to 40 Jackson turbidity units, JTU) than at the surface (approximately 25 JTU). Vessel passage (Test 23) caused a peak in turbidity of approximately 90 JTU. However, turbidity at the substrate-water interface declined after nearly 300 sec to slightly above ambient conditions. After 750 sec, no evidence of passage could be noted.

A smaller turbidity peak near the substrate-water interface was caused by Test 24 (Figure 4). The increase in turbidity occurred immediately before the vessel passed. This high value declined to near ambient levels within 2 min of passage.

Evaluating the Biological Consequences of Vessel Movement

Tolerances of many aquatic organisms to sustained, specific levels of turbulence, water velocity, or suspended solids is known either from laboratory or field studies. Since vessel passage causes a brief and sometimes minor physical disturbance (Figure 1), most laboratory tolerance studies or field observations are not applicable. Intermittent disturbances caused by vessel movement, pulses of suspended sediments, changes in water velocity, and periods of desiccation can be simulated in the laboratory.

Navigation-related studies have been conducted on fish eggs (Morgan et al. 1976, Holland 1987), fish larvae (Holland 1987; Killgore, Miller, and Conley 1987; Payne, Killgore, and Miller, in press), plankton (Stevenson et al. 1986), and freshwater mussels (Aldridge, Payne, and Miller 1987; Payne and Miller 1987). Results of most studies demonstrated that mortality or physiological stress could be measured under conditions corresponding to high traffic intensity. However, in the field, discharge, flow patterns, bathymetry, and sediment characteristics have complex influences on vessel-induced disturbances. It is extremely difficult to estimate an organismal response to these intermittent physical effects, and it is even more difficult to accurately predict long-term responses of natural populations to such disturbances.

Results of the few navigation-related field studies that have been conducted are characterized by extreme spatial and temporal variability, so that clear patterns of navigation effects often cannot be discerned (Sparks, Thomas, and Schaeffer 1980; Bhowmik et al. 1981a, 1981b; Eckblad 1981; Environmental Science and Engineering, Inc. 1981; Seagle and Zumwalt 1981; Eckblad, Volden, and Weilgart 1984; Holland 1986). Ambient hydrologic conditions often overwhelm navigation effects (Johnson 1976).

Planners and biologists must evaluate the effects of man's activities on populations of species in their natural habitats. Whether as an alternative to or in validation of laboratory simulation, field studies should be used to evaluate the biological effects of tow-induced disturbances. Field studies should provide quantitative data on biotic parameters such as density, relative species abundance, community composition, population demography, and rate of growth. Adequate baseline data should be established, and then additional studies can be conducted to determine whether commercial navigation causes measurable change.

Since commercial traffic affects an entire waterway, planners and conservation groups frequently desire a "system-wide" quantification of environmental impacts. However, it is more practical to identify and study specific sites with special biological value that are among the most likely to be affected by commercial traffic. Results can then be extrapolated to similar sites.

3 Use of Quantitative Data on Mussels to Assess Habitat Quality

Importance of Freshwater Mussels in Rivers of the United States

Freshwater mussels dominate the benthic biomass in most large rivers in the United States (Fuller 1974). Their sedentary lifestyle and reliance on suspended particulate organic matter as food make them particularly susceptible to turbulence, sedimentation, and fluctuating water levels. Sparks (1975), Sparks et al. (1979), and Lubinski et al. (1981) suggested that decline of freshwater mussels in navigation channels could be caused by commercial traffic. Assumptions were based largely on the knowledge that mussels require stable gravel shoals free of sedimentation.

Shells of common unionids (principally *Amblema plicata plicata* (Say, 1817), *Megalonaias nervosa* (Rafinesque, 1820), *Quadrula quadrula* (Rafinesque, 1820), and *Fusconaia ebena* (I. Lea, 1831)) are used in the cultured pearl industry (Fuller 1974, Sweaney and Latendresse 1982, Sitwell 1985). Commercially valuable species are collected by divers or with a brail (Coker 1919) and then shipped to the Orient and processed into inserts. In the United States, 25 unionid species are listed as endangered by the US Fish and Wildlife Service (1987). Willful destruction of these species or their habitat by a Federal agency is prohibited.

Quantitative Studies on Mussels as an Assessment Tool

Because freshwater mussels are long-lived and relatively nonmotile, regular quantitative assessments of their populations and communities provide an index of habitat quality. This, in conjunction with their ecological value and the protected status of the endangered species, makes them ideal monitoring tools.

As part of studies on commercial traffic effects, we have been studying freshwater mussels since the early 1980's. Research has been conducted at historically prominent mussel beds in major rivers in the central United States. Studies are conducted to determine whether endangered species are present and, if so, whether they are likely to be affected by proposed developments. More detailed studies are designed to evaluate the environmental effects of commercial traffic, dredging, or other water resource developments on mussels. These data will also be used to evaluate the effects of the spread and colonization of zebra mussels, *Dreissena polymorpha* (Roberts 1990).

Quantitative techniques have been used for all studies, which are described in Miller and Payne (1988), Payne and Miller (1989), and Miller and Payne (1991b). The following examples illustrate the use of quantitative data on freshwater mussels to monitor aquatic habitats and evaluate the environmental impacts of commercial navigation traffic.

Demographic analysis of *Fusconaia ebena* in the lower Ohio River

The US Army Engineer District (USAED), Louisville, is planning to replace the last two locks on the lower Ohio River, Lock and Dam 53 (river mile (RM) 962.6) and Lock and Dam 52 (RM 938.9), with a single lock and dam at RM 964.4. The replacement will be located immediately upriver of a dense and diverse bed of freshwater mussels first identified by Williams (1969). The mussel bed is approximately 4 miles long and occurs on the channel border adjacent to the navigation channel. *Fusconaia ebena* is the dominant species, comprising approximately 70 percent of the unionid fauna.

The position of the new structure will cause vessels entering and exiting the lock to pass near the mussel bed. Quantitative studies on mussels were initiated at this site in 1983; more details appear in Miller, Payne, and Siemsen (1986) and Payne and Miller (1989).

Replicate quantitative 0.25-sq m substrate samples were collected by scuba divers in the fall during the years 1983, 1985, and 1987 at this site . Sediments were sieved (finest mesh size, 6.4 mm) to obtain all mussels regardless of size. Total shell length (SL) of each mussel was measured, and SL frequency histograms were plotted.

Seventy-one percent of all *F. ebena* collected in 1983 belonged to a single cohort of 1981 recruits with an average SL of 16 mm (range, 13 to 20 mm) (Figure 5). By the fall of 1985, this cohort had increased to an average SL of 30 mm (range, 23 to 38 mm) and still comprised 71 percent of the population. Continued linear growth led to an average SL of 47 mm by late September 1987 (range, 36 to 56 mm). Relative abundance of the cohort remained high (74 percent). Its sustained high relative abundance was a result of low mortality and lack of extensive new recruitment.

Fusconaia ebena has existed in this shoal bordering the commercial navigation lane in this reach of the river for decades (Williams 1969). Data clearly demonstrate that recruitment success is the principal determinant of abundance. Survival of the 1981 recruits has been high despite proximity of the shoal to a major commercial navigation lane.

The continued existence of unionids in large inland rivers depends on the protection of remaining beds from impoundment, dredging, or sustained degradation of water quality (Stansbery 1970) and the prevention of overharvesting. Assessments of the health of remaining mussel beds must be based on long-term quantitative studies of recruitment, growth, and survival of cohorts of dominant populations. Quantitative samples were also obtained in 1988 and 1990. The early cohort continues to grow, and there is evidence of only limited recruitment since the study began.

Analysis of recruitment of *Amblema plicata* in the upper Mississippi River

Techniques similar to those described above are also being used to study mussels in a side channel east of the Mississippi River near Prairie du Chien, Wisconsin (RM 635.0). A barge-loading facility is in the north end of the 3-mile-long east channel. The loading facility and dock principally handle grain and other agricultural products and has operated since the early 1960's. The east channel and an extensive reach of the main river support dense and diverse mussel populations, including an endangered species, *Lampsilis higginsi* (Havlik and Stansbery 1977).

Only the north end of the east channel is navigated, although the remainder is suitable for commercial traffic. Vessels must make a sharp turn in a turning basin as they approach or exit the loading facility. The basin is only 9 to 12 ft deep; it and adjacent areas were dredged in 1976.

The loading facility is serviced by a workboat that draws only 7.5 ft, although loaded barges require a 9-ft channel. (The physical effects of passage of this workboat with a loaded barge are illustrated in Figure 1.) In 1988 and 1989, 230 and 248 barges, respectively, were loaded and moved through the north end of the east channel.[1] Because the turning basin is shallow, the bottom is often scraped by loaded barges. Approximately 20 to 50 percent of the live mussels in the turning basin show

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[1] Personal Communication, 1991, Robert Reed, Wisconsin Department of Natural Resources, Madison, WI.

evidence of abrasion. The workboat also transports barges to and from another loading facility and dock that are reached without making a sharp turn in the north end of the channel.

Quantitative mussel samples were obtained in 1984-85 and 1987-90 using divers equipped with scuba or surface air supply. An experimental site was in the barge turning zone, and a reference site relatively unaffected by vessel movement was located about 0.5 mile downriver. The purpose was to determine whether vessels passing through the turning basin affected recruitment of *A. plicata*. This commercially valuable species usually comprises more than 50 percent of the fauna in this reach of the upper Mississippi River.

Amblema plicata were separated into groups less than and greater than 30 mm total SL. Smaller individuals are 3 years old or less, and evidence of fairly recent recruitment. The larger group contained individuals up to 120 mm SL; such specimens could be 20 or more years old. The maximum age of large unionids is difficult to determine using shell ring counts.

Density of mussels greater than 30 mm SL in the turning basin was significantly less ($p < 0.05$ for unpaired t test) than at the reference site for all years except 1989 (Figure 6a). Intersite density differences can be attributed to dredging in the turning basin in 1976, which removed substrate and live specimens.

However, no significant intersite density differences were noted for mussels less than 30 mm total SL ($t < 0.65$, $p > 0.05$ for all 6 years). This indicates that recruitment is proceeding at a similar rate at both sites regardless of earlier dredging and the continued use of the turning basin. Figure 6 indicates that intersite density differences are decreasing, partially because of recruitment and growth of younger cohorts. The density decline after 1985 of large individuals at the reference site is unrelated to traffic and is probably the result of mortality of older cohorts.

4 Use of Habitat Suitability Index Models

Background

Consideration has been given to using Habitat Suitability Index (HSI) models, developed primarily for the Habitat Evaluation Procedures (US Fish and Wildlife Service 1981), to predict the environmental effects of increased navigation traffic. Models that evaluate quality of habitat for fish and wildlife populations are often used by state and Federal agencies to predict ecological consequences of water resource developments. The HSI models have been used to analyze changes in habitat quality and quantity relative to populations of terrestrial and aquatic animals. The strength of these procedures lies in their ability to predict loss in value based upon with- and without-project conditions. Some consideration has been given within Federal agencies to the use of HSI models for predicting the environmental effects of increased commercial navigation traffic.

The HSI models provide a mechanism for placing a numeric value on existing habitat conditions for a species or group of species. Changes in habitat quality are predicted from knowledge of project alternatives. Simple quantitative models are used that relate habitat features (i.e., water depth, velocity, substrate type, and presence of cover, for most aquatic species) to an area's suitability for a particular species. These models are usually based on field and laboratory data. However, data are often unavailable, and models are then based on the opinion of experts. Models are actually working hypotheses of the habitat requirements of populations.

Application of HSI models has generally been restricted to projects involving habitat conversion, such as that which occurs when streams or bottomland woods are flooded by the construction of dams. For such major conversions, simple quantitative models can be employed that are based on fundamental aspects of species-to-habitat relationships.

Effects of Traffic on Riverine Habitats

An increase in commercial navigation traffic does not affect basic attributes of habitat, such as water depth and velocity, presence of cover, and substrate type. Additional traffic in a waterway causes an increase in relatively subtle and complex habitat factors, such as pulses of turbulence, suspended solids, wave wash, and drawdown. These changes that relate specifically to traffic cannot be readily predicted or measured. Furthermore, biological consequences of traffic-induced habitat changes are not well known. Conversely, the major habitat conversions (i.e., changes in water depth or substrate type associated with reservoir construction) are easily predicted.

The magnitude and duration of traffic-related effects can vary within and among sites because of variables such as bottom topography, sediment type, and discharge. Furthermore, concern is usually expressed over the incremental increases in traffic in a waterway that has supported commercial navigation for many years. The scouring of bottom sediments by propeller wash of passing tows in a newly completed waterway will change sediment conditions. Habitats with fine-grained sediments could quickly be converted to scoured clay or rock.

Following these initial changes, subsequent passages would have relatively minor effects. Increased traffic does not alter the basic aspects of physical habitat, such as water depth and velocity, cover, and sediment characteristics.

Schamberger and O'Neil (1986) enumerate the requirements that habitat variables must meet in order to be included in an HSI model. They state that variables must (a) be vulnerable to change during the course of a project, (b) be readily estimated or measured, (c) be predictably changed in value under future conditions, (d) elicit species responses, and (e) be influenced by project planning or management. Careful consideration of these requirements shows that satisfactory HSI models cannot be built to evaluate the effects of an incremental increase in commercial navigation traffic.

Variables that are sensitive to an incremental increase in navigation traffic, such as periodic increases in turbulence and suspended solids, cannot be easily measured or estimated. Discharge, flow patterns, bottom topography of the navigation channel and adjacent areas, sediment characteristics, and tow passage characteristics have complex influences on variables impacted by commercial navigation.

Results of the few field studies that have been conducted are characterized by extreme spatial and temporal variability, such that clear patterns of navigation effects often cannot be discerned (Bhowmik et al. 1981a, 1981b; Eckblad 1981; Environmental Science and Engineering, Inc. 1981; Eckblad, Volden, and Weilgart 1984). These studies do not suggest general relationships between habitat conditions and traffic intensity, and information on local physical conditions throughout large navigable rivers is insufficient to develop trustworthy models (Simons et al. 1981).

In addition, data are insufficient to predict when, where, and to what extent future navigation effects will be manifest. Since present conditions are so ill-defined, future habitat conditions cannot be predicted in terms of those variables that are sensitive to an incremental increase in navigation traffic. This holds true despite the fact that economically based forecasts can be used to predict future traffic rates.

The requirement that changes in habitat values must elicit species responses must be carefully considered. Obviously, the responses elicited must clearly bear on the well-being of the population. In general, habitat suitability as predicted by an HSI model should relate to carrying capacity (Schamberger and O'Neil 1986). The biological consequences of intermittent increases in turbulence, suspended solids, and desiccation have been studied for larval and adult fishes. However, egg and larval fish mortality may have little bearing on the ultimate standing stock of adult fish. Water quality, spawning habitat, food availability, and predation can have overwhelming effects on carrying capacity for adult fish.

Finally, variables in an HSI model must be affected by project planning and management. Realistically, short of setting limits on allowable rates of traffic (which is very unlikely), planning or management of commercial navigation traffic cannot reduce intermittent increases in turbulence, suspended solids, or drawdown.

Summary

Habitat suitability modeling was not intended as a predictive technique for subtle, complex alterations of a habitat. Instead, HSI models have been developed for projects in which entire parcels of habitat are converted from one type to another type (e.g., Verner, Morrison, and Ralph 1986). It is not unreasonable to use simple, deterministic models of species-to-habitat relationships to quantify habitat conversions, although much uncertainty surrounds even these relatively straightforward analyses (O'Neil and Carey 1986). However, it is unreasonable to use HSI models to quantify the consequences of complex and subtle alterations of physical habitat that result from incremental increases in navigation traffic.

The habitat variables that are vulnerable to incremental increases in traffic are not suitable for an HSI model. These variables are not easily estimated or measured, and they cannot be predicted for future conditions. In addition, the animal responses they elicit are vaguely understood, and planning and management options that can modify the effects of traffic on these variables do not exist.

5 Long-Term Study, Upper Mississippi River System

Background

In the late 1980's the USAED, St. Louis, began construction of the Melvin Price Locks and Dam to replace Locks and Dam 26 located on the Mississippi River near Alton, IL. The new structure will have two chambers--one 1,200 ft long for commercial tows and a 600-ft auxiliary chamber. Since the original structure consisted only of a 600-ft chamber and a smaller auxiliary chamber (360 ft), the new facility will greatly reduce traffic congestion. Previously, delays up to 72 hr were common.

This is a critical segment of the waterway; 15 miles north is the confluence of the Illinois River, which leads through the Chicago Ship Canal to Lake Michigan, and 10 miles south is the confluence of the Missouri River. The lock is 200 miles upriver of the confluence of the Ohio River, which ultimately connects with the Tennessee, Cumberland, Allegheny, and Monongahela Rivers.

The US Fish and Wildlife Service and state conservation groups indicated that the potential for increased traffic above the new lock could negatively affect aquatic resources, especially the endangered *L. higginsi* (US Fish and Wildlife Service 1986). In accordance with the Endangered Species Act, Section 7, Consultation, a monitoring program was initiated in 1988 to assess the effects of projected traffic increases.

Research was designed to obtain data on physical effects of commercial vessel passage (changes in water velocity and suspended solids near the substrate-water interface) at dense and diverse mussel beds where *L. higginsi* was found. In addition, important biotic parameters (such as species richness, species diversity, density, growth rate, and population structure of dominant mussel species) are being monitored every second year. Data are being collected on community and population parameters to determine whether commercial navigation traffic is negatively affecting *L. higginsi*.

This surrogate species concept is being used since it is extremely difficult to obtain information on density, recruitment, and other biotic parameters for uncommon species. In addition, intensive collections of *L. higginsi* would be detrimental to its continued existence.

Study Design

Results of the reconnaissance survey (1988) and from six additional years (1989-94) of detailed study will provide baseline physical and biological information. Additional information to be obtained from studies scheduled for the years 1995 through 2040 will be compared with the results from baseline studies to determine if commercial traffic is having negative effects. The following six parameters, considered to be indicative of the health of a mussel bed, will be used to determine if commercial navigation traffic is negatively affecting freshwater mussels:

- Decrease in density of five common-to-abundant species.
- Presence of *L. higginsi*.
- Live-to-recently dead ratios for dominant species.
- Loss of more than 25 percent of the mussel species.
- Evidence of recent recruitment.
- Significantly different growth rates or mortality.

Each mussel bed will be studied every other year until 1994; three nonconsecutive years of data can be obtained from each bed. Data will be collected during a period when traffic levels are not expected to increase. After 1994, biological and physical data will be collected at each bed once every 5 years. This will be done until traffic levels have increased by an average of one tow per day above 1990 levels in the pool where monitoring takes place. Studies will then resume at the original rate and continue until 2040, the economic life of the Melvin Price Locks and Dam Project. Results of these studies will be reviewed annually to determine the need for altering sampling protocol.

This experimental design will enable three types of comparisons:

- Comparisons within mussel beds.
- Comparisons among mussel beds.
- Comparison between (or among) study years.

Application of Results

The relationship between cumulative species of mussels (Y) and cumulative individuals (X) at one of the study sites on the upper Mississippi River provides a measure of the difficulty of obtaining uncommon species such as *L. higginsi* (Figure 7a). For example, in 1988, ten quantitative (0.25-sq m) samples were collected at RM 504.8. Twenty species were obtained after nearly 250 individuals had been collected. In 1989, thirty quantitative samples were collected. Additional effort yielded nearly 900 individuals and only three additional species. *Lampsilis higginsi*, which comprises about 0.5 percent of the mussel fauna at this site, was found both years. With appropriate sampling the mussel fauna was found to have a fairly even distribution, and spanned four orders of magnitude (Figure 7b).

Continuing studies will provide information to assess the effects of traffic on community composition and distribution, and the effort required to collect *L. higginsi*.

6 Conclusions and Recommendations

Conservation agencies in the US Federal and State governments have expressed concern over the environmental effects of commercial vessel movement. This has resulted in the publication of many reports, some speculative and without substantial data (see Wright 1982). Part of the problem is the extreme difficulty and expense of conducting field studies on traffic effects. Many species of freshwater mussels (and many fish species) live 20 or more years. At a minimum, definitive cause-and-effect studies should span a sizable segment of their life cycle.

At sites where important biotic resources exist (side channels or sites outside the navigation channel), the direct physical impacts of commercial vessel passage are usually minor (Figure 1). This information is not new; Environmental Science and Engineering, Inc. (1981), published data similar to these. In shallow water, commercial vessels can dislodge, scrape, or even kill aquatic organisms.

However, in studies conducted near Prairie du Chien, WI, the number of traffic events per year (less than 300) is not negatively affecting the structure of the *A. plicata* population. Results of studies on heavily trafficked waterways in Europe (Murphy and Eaton 1983, Brookes and Hanbury 1990) and laboratory experiments by Payne and Miller (1987) suggest that extremely high traffic intensities would be needed to affect certain aquatic organisms.

Although laboratory experiments provide insight into possible impacts of physical stress to natural populations, definitive empirical data can only be obtained by long-term field studies. In the United States, and certainly in most developed countries, Federal Governments are in a position to sponsor such research. Their established missions with respect to waterways and potentially stable funding bases are important components of monitoring programs.

Predictions on the impacts of controlled use of natural resources should not be based on results of a single laboratory experiment or one-time field observations. Key biotic parameters should be regularly monitored, similar to the manner in which data are assembled on river discharge, precipitation, or air temperature.

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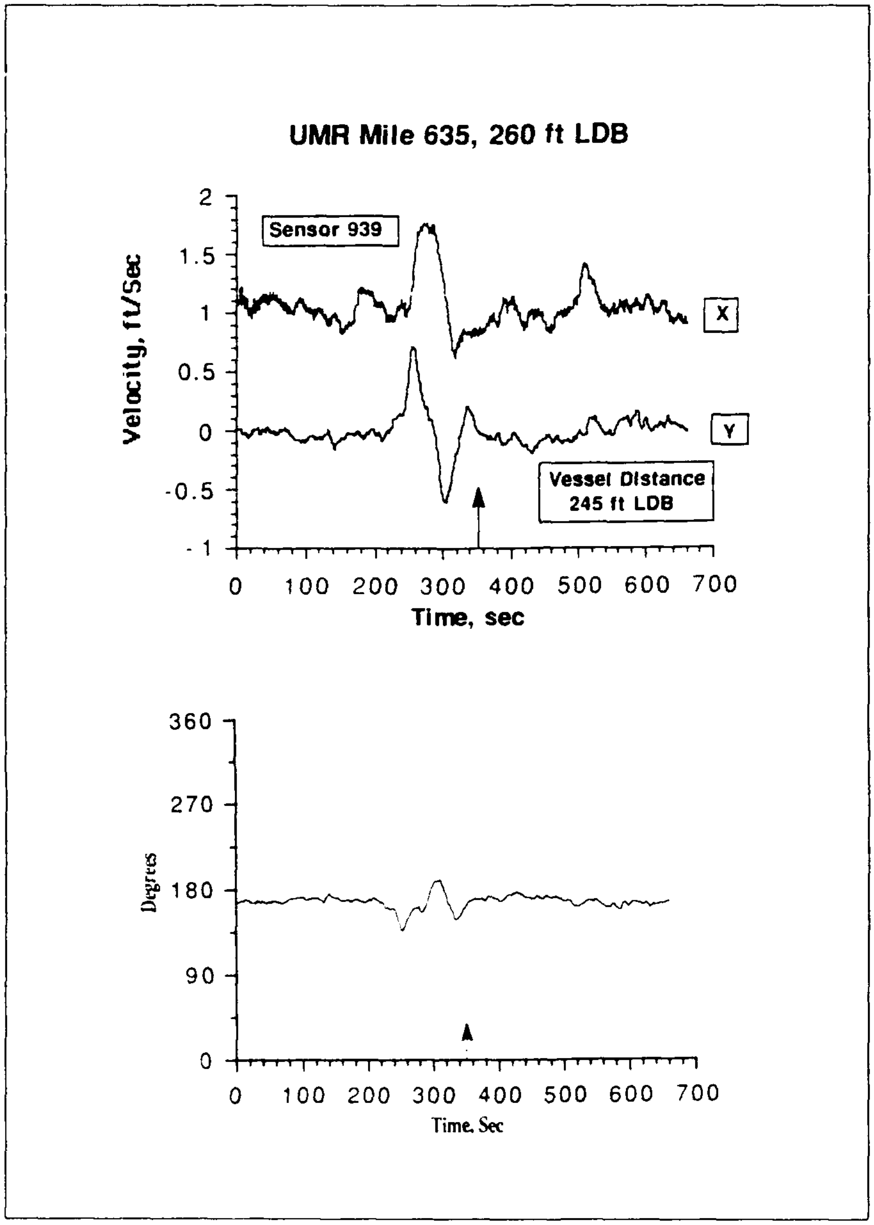


Figure 1. Change in ambient water velocity parallel to flow (X) and at right angles to flow (Y) (upper), and change in direction (lower), caused by passage of an 800-hp workboat moving upriver in the east channel of the Mississippi River, near RM 635.0. The vessel passed directly over the sensor of a Marsh McBirney 527 sensor positioned 9 in. above the substrate-water interface. Water depth was 13 ft (after Miller and Payne 1991b)

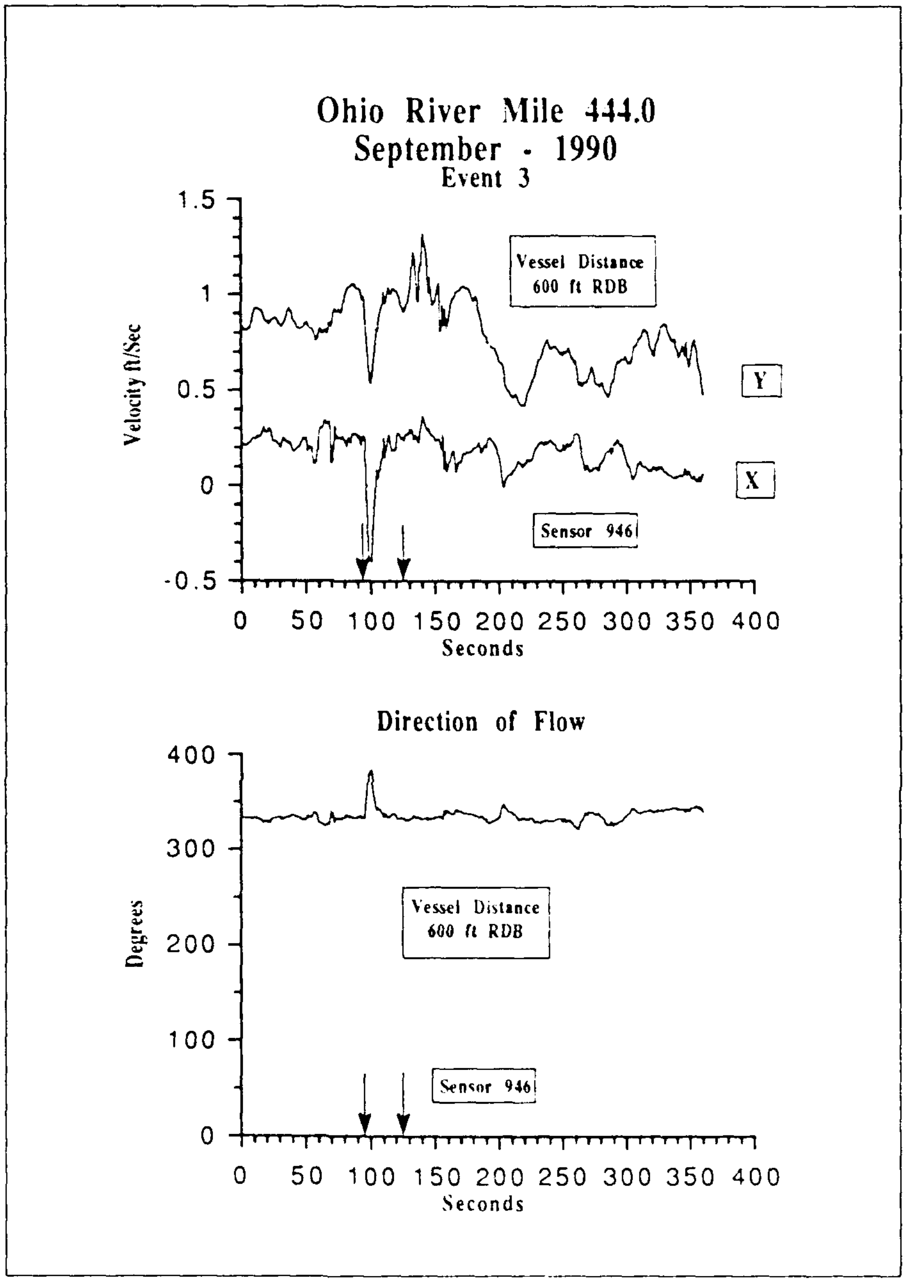


Figure 2. Change in ambient water velocity parallel to flow (Y) and at right angles to flow (X) (upper) and change in direction (lower), caused by passage of a tugboat with three unloaded barges moving downriver on Ohio River, RM 444.0 (Miller and Payne 1991c)

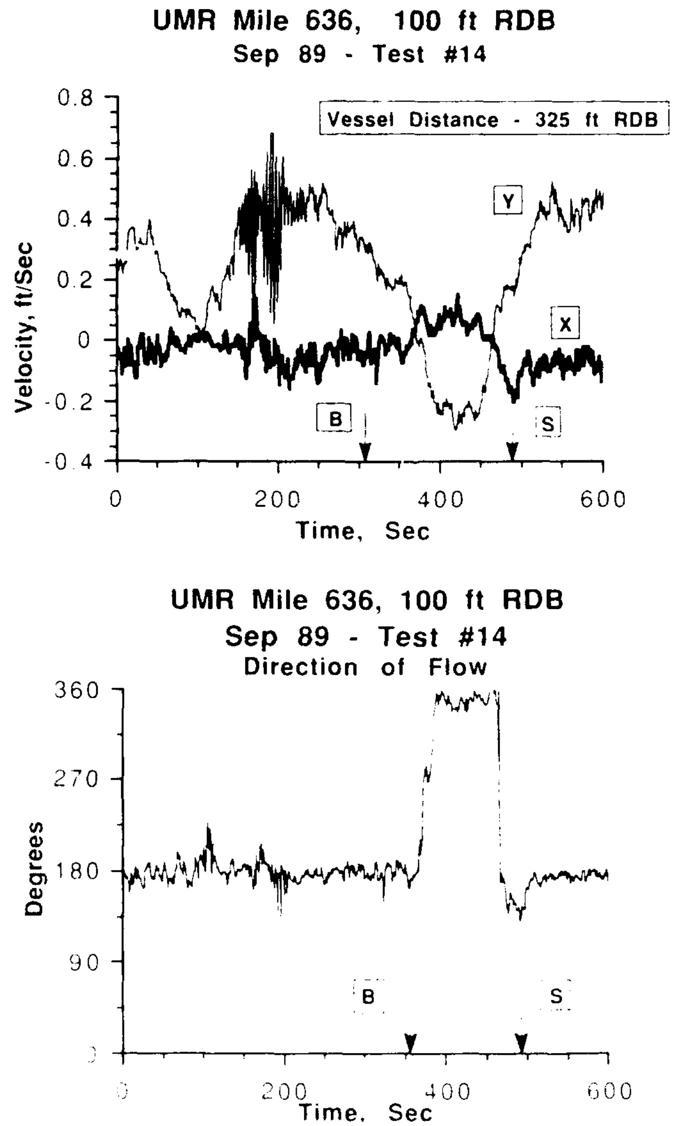
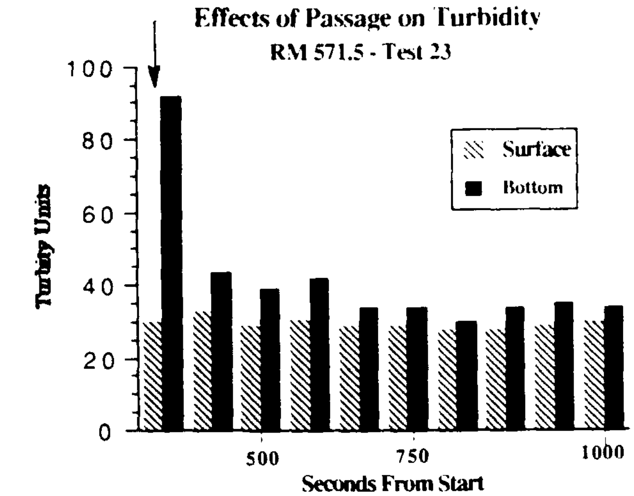


Figure 3. Change in ambient water velocity parallel to flow (Y) and at right angles to flow (X) (upper), and change in direction (lower), caused by passage of a tugboat with 13 loaded barges moving downriver on Mississippi River, RM 636.0 (from Miller and Payne 1991a)



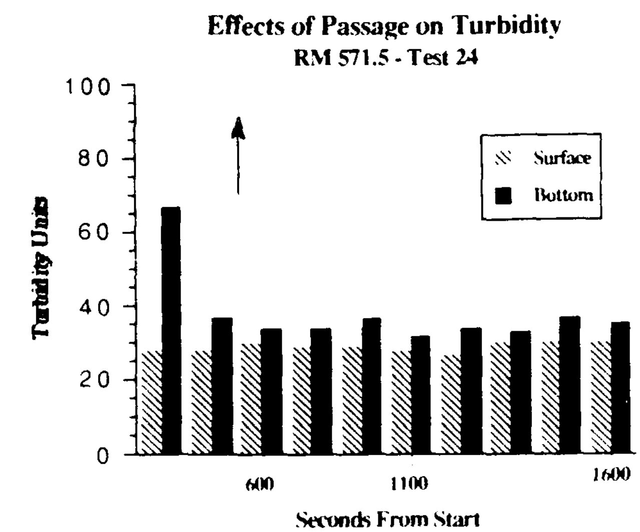


Figure 4. Changes in turbidity associated with passage of a commercial vessel in the upper Mississippi River, July 1989 (Miller and Payne 1991d)

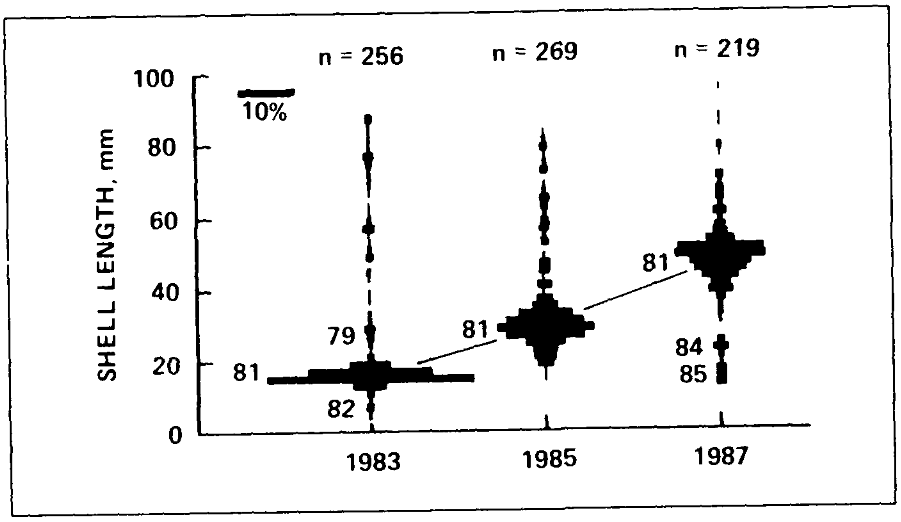


Figure 5. Shell length frequency histograms for *Fusconaia ebena* collected in the lower Ohio River (after Payne and Miller 1989)

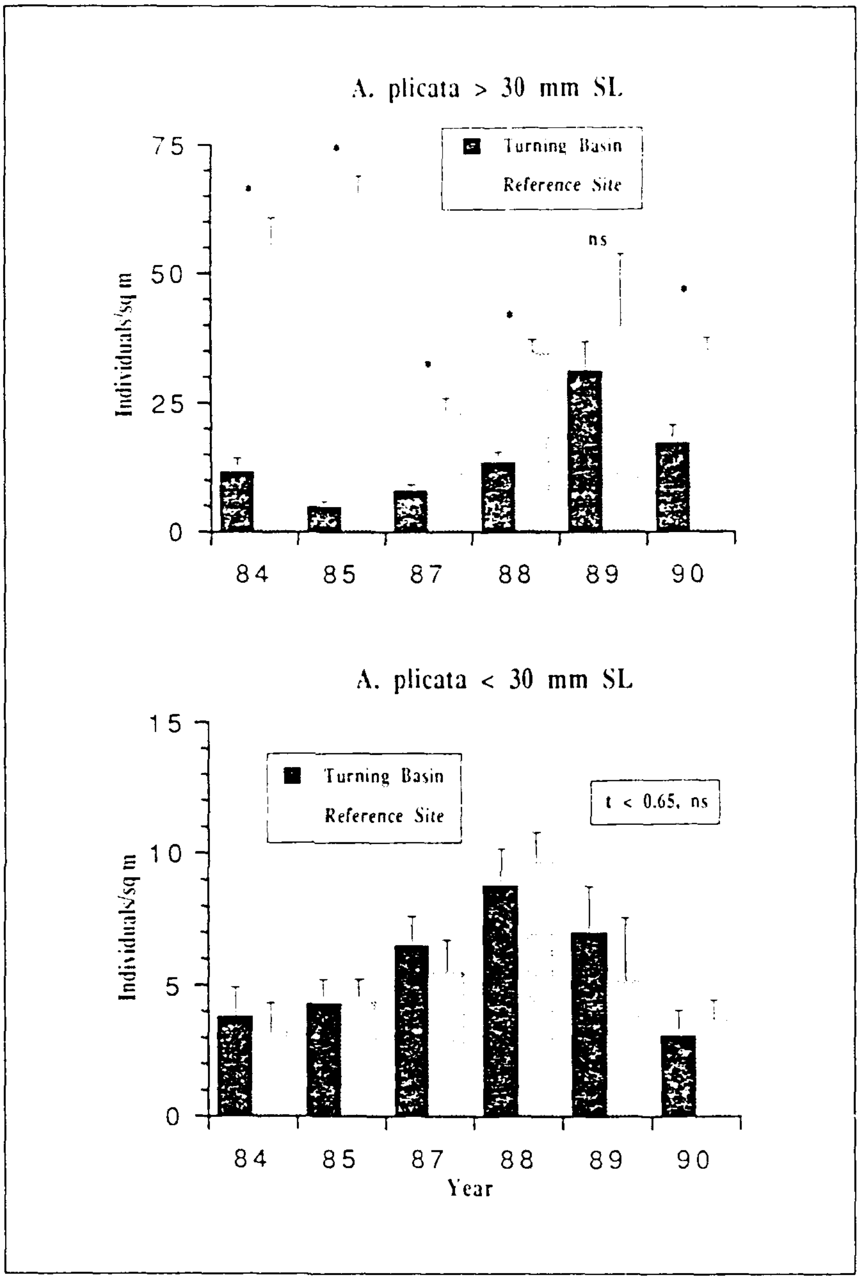


Figure 6. Total density (individuals/m^2) for *Amblema plicata* greater than (upper) and less than (lower) 30-mm total SL in a barge-turning basin and a reference site located downriver. For mussels greater than 30 mm total SL, intersite differences were significantly different ($p < 0.05$, denoted with an asterisk) except for 1989 (ns). For mussels less than 30-mm total SL, intersite density differences were not significantly different (after Miller and Payne 1991b)

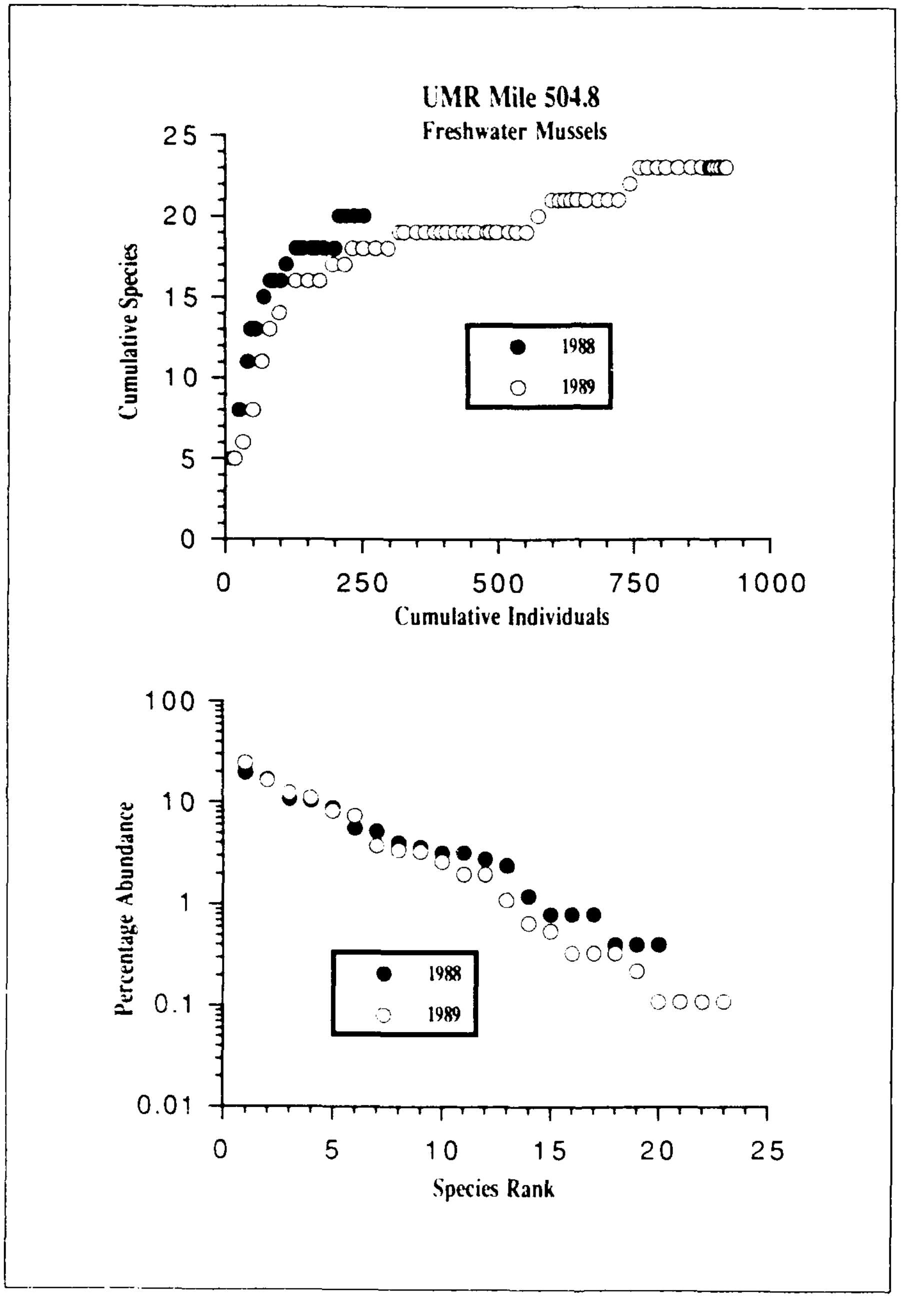


Figure 7. Relationship between cumulative species and cumulative individuals (upper) and percent abundance and species rank (lower) for freshwater mussels collected in 1988-89. (See text for details) (from Miller and Payne 1991a)